LINE PILOTS' ATTITUDES ABOUT AND EXPERIENCE WITH FLIGHT DECK AUTOMATION:
RESULTS OF AN INTERNATIONAL SURVEY AND PROPOSED GUIDELINES

Dr. Marianne Rudisill
NASA Langley Research Center
Hampton, VA 23681-0001

ABSTRACT

A survey of line pilots' attitudes about flight deck automation was conducted by the Royal Air Force Institute of Aviation Medicine (RAF IAM, Farnborough, UK) under the sponsorship of the United Kingdom's Civil Aviation Authority and in cooperation with IATA (the International Air Transport Association). Survey freehand comments given by pilots operating 13 types of commercial transports across five manufacturers (Airbus, Boeing, British Aerospace, Lockheed, and McDonnell-Douglas) and 57 air carriers/organizations were analyzed by NASA. These data provide a "lessons learned" knowledge base which may be used for the definition of guidelines for flight deck automation and its associated crew interface within the High Speed Research Program. The aircraft chosen for analysis represented a progression of levels of automation sophistication and complexity, from "Basic" types (e.g., B727, DC9), through "Transition" types (e.g., A300, Concorde), to two levels of glass cockpits (e.g., Glass 1: e.g., A310; Glass 2: e.g., B747-400). This paper reports the results of analyses of comments from pilots flying commercial transport types having the highest level of automation sophistication (B757/B767, B747-400, and A320). Comments were decomposed into five categories relating to: (1) general observations with regard to flight deck automation; comments concerning the (2) design and (3) crew understanding of automation and the crew interface; (4) crew operations with automation; and (5) personal factors affecting crew/automation interaction. The goal of these analyses is to contribute to the definition of guidelines which may be used during design of future aircraft flight decks.

INTRODUCTION

There has been a significant impact brought about by the progressive introduction of automation technologies onto commercial transport flight decks. The majority of these enhancements have been positive. For example, automation has allowed more efficient flight path management, a reduction in crew workload resulting in certification of the two-pilot cockpit, new crew interface features, and more efficient use of cockpit "real estate." However, human factors problems with ever-more complex flight deck automation have also been noted. Wiener and Curry (1980) foreshadowed these problems, while researchers such as Wiener (1989), Sarter and Woods (1991), and Norman and Orlady (1989) added to our knowledge. The pilot/automation interface has been implicated in accidents involving "glass cockpit" aircraft (e.g., Sparaco, 1994; Mecham, 1994), prompting guidelines for "human-centered aircraft automation" (Billings, 1991) and, more recently, a review of automated cockpits and their crew interfaces (Hughes and Dornheim, 1995). A systematic analysis of crew experiences with automation --that is, "lessons learned" from line experience--may aid in the definition and enhancement of human factors guidelines for the design and use of future automated flight decks.

METHOD

An Automation Attitudes Survey was distributed by the RAF IAM and IATA to commercial transport pilots within the United Kingdom, North America, Europe, the Middle East, Asia, Australia and New Zealand. All surveys were confidential. The survey consisted of four sections: biographical information (e.g., age, crew position); ten bipolar statements to determine level of experience with glass cockpits; 78 bipolar statements addressing specific issues with regard to automation (e.g., training, display usage); and an open section for freehand comments. A total of 1,914 completed surveys was returned for analysis. Principal Components Analyses of the bipolar statements were performed by the RAF IAM and have been reported in the human factors literature (James, McClumpha, Green, Wilson, & Belyavin, 1991; McClumpha, James, Green, & Belyavin, 1991). The present report addresses preliminary results of ongoing analyses being performed by NASA of the survey freehand comments.

Thirteen commercial transport aircraft types were selected for analysis (inclusion of versions within selected aircraft types translated into a total of 15 aircraft categories). Four levels of automation complexity were defined and the 15 aircraft were ranked according to these definitions. The first automation complexity level was "Basic" (e.g., B727; DC9). A Basic cockpit has only simple flight instruments and rudimentary navigational instruments which are not generally integrated in display. There is an autopilot and a flight director. The orientation and

monitoring of the flight profile is done solely by the pilot and simple computer assistance is provided in the form of steering information for the pilot to perform The second automation complexity level, "Transition" (B737-300; A300; DC10), implies a cockpit with an onboard navigational system integrated into a computer-based flight profile monitor. The navigation system may be ground-based, OMEGA, VOR/DME (Very high frequency Omnirange/distance measuring equipment), or inertial; however, the autopilot follows the navigational instructions and usually is able to autocouple to an ILS (Instrument Landing System) at Category II (ILS approach procedure to a height above touchdown of not less than 100 feet, with runway visual range not less than 1,200 feet) as a minimum approach aid. Vertical navigation guidance is provided to fly a more efficient flight profile. There were two "glass" levels of automation complexity. "Glass 1" cockpits (e.g., A310; B737-400) have a fully-automated flight system with CRT (cathode ray tube) displays of flight instruments and navigational information. Navigation and flight profile are programmable and automatically monitored, with the autopilot flying most of the time. This cockpit has a full EFIS (Electronic Flight Instrumentation System) and FMS (Flight Management System). The autoland capability is usually Category IIIB (ILS approach procedure without a decision height maximum and with runway visual range not less than 150 feet), often with roll-out and low visibility takeoff guidance. The highest level of automation complexity, "Glass 2" (e.g., A320, B757) includes all of the Glass 1 features with the addition of systems automation (e.g., EICAS [Engine Indication Caution and Alerting System] and ECAM [Electronic Centralized Aircraft Monitor]).

Freehand comments were analyzed within each aircraft category and were collapsed within a single automation complexity level. The numbers of respondents and respondents providing comments (and, therefore, serving as the basis for these comments analyses) by aircraft type and level of automation complexity are provided in Table 1. For the purposes of brevity, this report focuses on the results of analyses of freehand comments provided by pilots flying the highest level of automation complexity, Glass 2 (a detailed description of all comments analyses is in preparation). The Glass 2 aircraft analyses are based on a corpus of comments from 443 respondents (56 + 107 + 280) flying three aircraft types (A320, B747-400, B757/767). Respondents included Captains (N=249), First Officers (N=175), and Second Officers/Flight Engineers (N=12) working for 20 air carriers (two respondents were retired and five gave no crew position). Pilots flying Glass 2 category aircraft had a mean of 1161 hours on their respective types with a mean of 9378 total flight hours. Mean age was 42 years with a mean of 20 years of professional flying. Therefore, analyses of crew comments within the Glass 2 category were based on all crew positions with pilots having broad experience across a number of airlines.

Table 1
Numbers of Respondents & Respondents Providing Comments by Aircraft Types & Automation Complexity Level

	Respondents (N)	Respondents providing comments (N)
Basic		
B727 / 727-200	16	8
B737-200	85	25
DC9	14	3
Transition		
A300	13	10
B737-300	153	103
B747-100 / 200 / 300	148	72
DC10	22	10
L1011	61	34
Concorde	7	3
Glass 1		
A310	102	34
B737-400	120	80
MD-80	6	3
Glass 2		
A320	83	56
B747-400	176	107
B757 / 767	464	280

A method for systematically categorizing crew comments was developed by reviewing a random sample of approximately 400 surveys. Five broad categories of comment types were defined. (1) General comments related to such factors as safety and general good/poor things about flight deck automation. (2) Design comments fell into two subcategories, those relating to the crew interface and those relating to the underlying philosophy of automation design and its use. (3) Comments in the Understanding & Automation Use category involved crew understanding of automation and related systems (e.g., Flight Management System). (4) Crew Operations comments described the relationship of automation to crew workload, trust, training, and cockpit operations, and the impact of automation on airmanship and skills. (5) Crew Personal Factors comments described the relationship between automation and specific crew factors, such as age and experience.

RESULTS

General issues related to automation

With regard to flight safety, the general consensus was that safety is increased with automation. Specifically, automation allows more "thinking and monitoring" time, is less fatiguing, and produces a less stressful work environment. However, there were specific concerns with automation. Automation may lend a false sense of security, particularly with inexperienced pilots. It may also produce a higher sense of "insecurity" during an automation failure. Pilots believe there is a general temptation to ignore raw information and "follow the green/magenta line." In addition, there was general concern that automation may increase boredom, thereby indirectly decreasing safety. Automation was seen as a progressive step in the right direction in that it allows more accurate and efficient airline operations. However, several areas of possible improvement were noted.

Design

Flight deck designs were considered to be generally good, but design problems with specific aircraft were reported. Initial problems with software seem to have been reasonably cured. There is a significant positive response to the map display. The typical EFIS presentation is very usable, but it "takes getting used to." Several specific problems were noted with regard to displays and crew interaction with automated systems; for example: map shift; difficulty with airspeed and altitude tapes; information clutter; presentation of engine secondary data; indecipherability of messages (e.g., due to poor wording and poor use of abbreviations); incorrect feedback (e.g., fuel predictions); improper signaling (e.g., of V_2 climb-out speed); overall lack of feedback from systems; irrelevance of some displayed data; slow system activation and response time; extreme complexity with failures; and variable reliability and false/spurious warnings of automated systems. With regard to controls and the underlying flight control philosophy, the response to fly-by-wire is very positive; however, there is an overall negative response to the perceived lack of feedback from the fixed autothrust system and auto-trim (e.g., "the seat of the pants is gone...") and lack of cross-cockpit and autopilot control coupling.

Understanding and Automation Use

Generally, pilots report an overall positive response to automation elements and their integration. They believe automation allows them to concentrate on the "real world outside" and makes aircraft handling easier. In particular, the navigation information is considered very good and pilots appreciate the option to "turn off" the automation and revert to basic flying skills. However, there were several concerns with regard to the use of the automation. Pilots noted that automation requires more self-discipline--it "makes things too easy," and they may find themselves in "traps" that lead to accidents and incidents. In glass cockpits, it is easier to be "drawn in" and lose sight of the aircraft; that is, it is easier to become a "spectator" and lose awareness of ongoing operations. In particular, careful monitoring of mode annunciations is extremely important. Pilots also report feeling somewhat isolated or distanced from the physical aircraft. For example, pilots noted great difficulty in anticipating aircraft behavior. In addition, the "thought process" of flying is different (i.e., "flying through the computer" rather than directly controlling the aircraft) and time is required to adapt to this method.

Pilots also reported a strong sense of "over-automation," i.e., technology for the sake of technology rather than a clear requirement for an automated feature and sufficient consideration of operational and practical experience in its design. They report that interactions with the FMS, in particular, are very complex. Pilots find FMS programming to be time-consuming and that the automation cannot deal adequately with ATC changes. Some reported lack of confidence in their ability to program the FMS; "what's it doing now" is still common, although it tends to happen primarily during the first six months of line flying. Pilots also believe the crew role is being redefined by

automation; they are now "monitors" -- a role with which they are uncomfortable and for which they were not trained. They believe that automation is a tool that should complement the crew and must be under crew control; they object strongly to company-mandated use of automation. There is also a concern with preoccupation with the FMS during flight -- the "both heads in the cockpit" syndrome. This appears to be more pronounced with less experienced pilots. Some pilots proposed that "FMS fiddling" be restricted below 10,000 feet. Also, pilots believe that the notion "one pilot handles the FMS, the other handles the aircraft," should be emphasized in crew procedures and during training, because of the prevalence of this problem.

Impact of automation on crew operations

As has been reported in earlier studies (e.g., Weiner, 1989), automation may reduce workload in low workload flight phases and may increase workload in high workload flight phases; also, workload may be increased dramatically during abnormal situations and failures. Navigation capability and associated displays were noted as major workload reducers. Because of the high workload associated with interacting with the FMS, in particular, some crews have adopted the practice of predicting ATC (Air Traffic Control) instructions and "preprogramming" them into the FMS to reduce workload during final approach, even though this is not dictated by company SOPs (standard operating procedures). A number of pilots noted that it is often easier to just turn off the automation and "go manual" because of the workload penalty paid by the complexity of interactions with the automated systems.

With regard to trust in automation, pilots have some reservations. They report good, but variable, reliability; i.e., some automated systems are reliable; others are not. However, their primary concern is that many pilots report observing colleagues who become complacent and rely too much on the automation. A number of reasons were given for this "complacency": some pilots are "lazy" or over-confident in their ability to operate the equipment; some company policies and SOPs mandate reliance on automation; some training programs encourage pilots to rely on automation and may reduce individual initiative; and some training programs do not emphasize enough the need to cross-check raw data.

Several comments were made relating to crew training and automation. Many pilots noted that the initial training program was very difficult and they felt unprepared for their first unsupervised flight. Insufficient information was provided concerning the actual aircraft and its systems, making it difficult to assess potential problems. They wished for more hands-on practice and more simulator time, to consolidate their knowledge. Some believe the training philosophy needs to be refocused and that attention should be given to the basics of flying and automation should be placed in this context, instead of concentrating primarily on the automated systems. Conversions "up" to automated aircraft were not a problem (other than those associated with the amount of information and the new approach to flying); conversions "down" were disconcerting--scan and basic manual skills deteriorated or changed with automation use. Pilots reported a long learning curve: six months to one year of line operations is required to fully understand the FMS. Also, the regulatory authority requirements during periodic checks do not reflect the reality of operating automated cockpits. A primary concern expressed is that present training methods may produce an "era of button-pushers," not pilots.

With regard to cockpit operations, there is a belief that major incidents were primarily due to poor flight deck communication, a condition certainly not unique to automated flight decks. It is reported, however, that there is an enhanced need with automation for crew discipline, a clear division of duties, and maintenance of both pilots in the loop. With automation, crew communication tends to be more visual, less verbal. That is, communication is often dependent on the automated system visually reflecting a crew member's input; therefore, communication can be diminished if a crew member's interaction with an automated system is not mirrored.   Some pilots felt that there was an ongoing redefinition of crew roles and that "authority for manipulating the aircraft can shift subtly" based upon which crew member was actually operating the FMS. They believe that new SOPs are required to utilize the unique capabilities of the automated flight deck. Pilots report two problems when interacting with ATC: first, ATC does not adequately use automated aircraft capabilities and, second, ATC needs to appreciate the difficulty and workload involved in requiring the crew to reprogram the FMS.

Automation may reduce crew airmanship and basic skills, even though, "Automation has not changed the fundamentals of airmanship. Keeping air under the wings, knowing your position in space, being in the right configuration, are still as important as ever." Pilots reported a decrease in confidence in their handling abilities, a loss of (or change in) scan, and a decrease in navigation/position awareness. Many pilots reported increased self-discipline in "turning off automation" and regularly practicing manual flying. They believe management should encourage this behavior and must not mandate use of automation over hand-flying.

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Crew Personal Factors

Pilots believe that automated aircraft are generally less stressful and less fatiguing to fly (although there may be increased boredom, which in itself may cause problems). As noted earlier, the need for self-discipline is enhanced because the automation may lull you into a false sense of security. The primary concern with regard to crew personal factors involved experience level: more experienced pilots are apprehensive with the placement of inexperienced pilots on highly automated flight decks. Also, a number of experienced pilots commented that younger, inexperienced pilots are "computer keen," that they "fixate" on the automation, and their lack of experience prevents them from "knowing when to throw it away." They recognize that younger pilots grasp the fundamentals of automation faster than older pilots because of their general computer experience, but their lack of experience with conventional aircraft provides no knowledge base to rely upon in the event of an automation failure. Experienced pilots maintain that training pressures may not allow the development of basic piloting skills and also note that inexperienced pilots appear less aware of such flight fundamentals as airspeed, altitudes, and navigation.

EXAMPLE PROPOSED GUIDELINES

The goal of this research is to contribute to the definition of human factors guidelines which may be used in the design of future automated flight decks and the context within which they are operated. Example guidelines, derived from the results reported above, follow. It should be noted that some of these guidelines may already be implemented within present automated flight decks. In addition, these proposed guidelines were derived from pilot opinion and need to be validated prior to their application.

Design
• Pilots believe that development of "perfect" software with complex software-based systems is not possible. Consideration should be given to "not automating" some functions (even if the functions are "automatable") to lower risks associated with these types of systems.
• Review the design of the map display and enhance it; it is widely used by crews. Ensure the map display correctly reflects present position (i.e., solve the map shift problem).
• Provide a human factors review of the following and enhance the design: airspeed tape, altimeter tape, information clutter, engine secondary data presentation, and system messages.
• Review the overall system feedback scheme; identify and correct incorrect feedback and improper signaling.
• Failures of automated systems are complex and difficult for crews to manage. Simplify the interface such that it aids crews in decision making and in rectifying the problem.
• Provide physical feedback with, and cross-cockpit coupling of, flight controls. When considering "passenger comfort" in the design of automated flight controls, do not remove the "seat of the pants" feeling, but design the automated flight controls such that the pilot feels "attached" to the aircraft.

Understanding and Automation Use
• Allow pilots to easily "turn off" the automation and revert to manual flying, and make this choice clearly apparent to the crew.
• Do not automate a function for the sake of technology; reference automation design to crew needs and operational and practical airline experience; justify all automation features. Understand that each automated feature must be trained and completely understood for its correct use.
• Automation should be a tool to be used by the crew and it should complement crew skills; automation should always be under crew control.
• Consider restricting crew interaction with the FMS to above 10,000 feet.

Impact of automation on crew operations
• Recognizing that automation may increase workload during high workload phases of flight, develop SOPs that address this problem (e.g., suggest information to be preprogrammed into the FMS prior to approach in preparation for a change in ATC instructions). Allow pilots to turn off the automation during high workload periods.
• Enhance crew training with regard to automation: describe the self-discipline required; focus on maintaining operational awareness; emphasize careful monitoring of modes; emphasize the "thought process" associated with flying automated aircraft (e.g., "flying through the computer"). Extend crew transition training to glass cockpits to allow more time to absorb such complex information. Provide more information concerning the aircraft and aircraft systems. Provide more hands-on training with the automated systems; allow use of the simulator for consolidating learning. Develop training procedures and SOPs to correct the problem of complacency. Emphasize during training

the need to not "fixate" on the automation, but to actively monitor it and cross-check to raw data. Automation use should be taught within a "basics of flying" context, rather than concentrating purely on the automated systems. Review the format of periodic checks and update them to the reality of glass cockpit line operations.

• Enhance crew awareness of the need for crew discipline, a clear division of duties, and maintenance of both pilots in the loop. Develop SOPs to support these goals. Design displays to clearly mirror crew inputs, understanding that much of crew communication in automated cockpits is visual. Develop new SOPs to fully utilize capabilities of the automated flight deck. Enhance ATC awareness of crew operations in glass cockpits.

• Enhance crew awareness of the potential reduction of basic airmanship and skills. Encourage crews to regularly practice manual flying and develop supporting SOPs.

Crew Personal Factors

• Provide guidelines to crews to support them in dealing with boredom in automated cockpits.

• Review the rules governing assignment of ab initio or inexperienced pilots to glass cockpits; consider providing a mechanism to allow inexperienced pilots to develop a firm base of piloting skills while operating highly automated aircraft.

SUMMARY AND CONCLUSIONS

In summary, we as a community now have several years of commercial transport experience with highly automated flight decks. A systematic review of line pilots' experiences with, and attitudes about, flight deck automation may be used to contribute to the design and development of future human-centered automated flight decks and a supportive operations context.

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